Quantifying and Prioritizing Opportunities for Canal Backfilling in Louisiana

by

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ABSTRACT

Canal backfilling-degrading and replacing the spoil adjacent to canals-has a wide range of potential benefits for the restoration of Louisiana coastal wetlands, but is not incorporated into current coastwide-scale restoration plans. This report seeks to characterize backfilling opportunities using GIS analysis of publicly available datasets to quantify and prioritize the area and distribution of spoil currently suitable for use as canal backfill.

I used multiple filters to select backfillable spoil features based on the stability of the surrounding landscape, feature size, and proximity to Congressionally-authorized navigation channels or active oil and gas wells. Even this much-reduced extent of spoil indicated significant opportunities for backfilling distributed throughout the Louisiana coast.

The Barataria, Mermentau, and Terrebonne hydrologic basins contained most of a total prioritized backfillable spoil area of approximately 10,775 hectares. The total is similar to the area of linear restoration projects included in Louisiana’s 2012 Comprehensive Master Plan for a Sustainable Coast. Coastwide canal backfilling could be accomplished for less than a third of the cost of those already-planned projects, and greater savings and performance could be achieved by combining backfilling with master plan projects whose footprints they intersect.

Rough estimates of the value of wetlands that could be created through canal backfilling are \$1.33 billion, or \$0.14 billion per year. Estimates of the net present value of a crash program of coastwide backfilling ranged as high as \$2.7 billion after 50 years.

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INTRODUCTION

I intend to show that canal backfilling opportunities in Louisiana are well within the scope and scale of current coastal restoration plans that have broad support from a variety of stakeholders, and that the benefits of backfilling significantly outweigh the costs. The analysis focuses on the spoil available for backfilling coastwide, identifies potential restoration areas, and highlights priorities based on several criteria. My intent was to use publically available data that required minimal processing to incorporate it into analysis, and that could be reasonably expected to be updated over time. The data I produced has potential utility for map production, additional analysis, and model input. This report provides a review of the relevant literature on canal backfilling in Louisiana, discusses the results of my analysis, and describes potential policy solutions that could encourage the use of canal backfilling in the state.

Background

Wetlands cover about six percent of the land on Earth (Mulvaney and Robbins 2011). They are a source of much value for people (Costanza and others 1997; Zedler and Kercher 2005), and are highly productive ecosystems (Smardon 2009; Zedler and Kercher 2005). However, they have traditionally been viewed negatively, and valued only when altered to suit narrow human interests (Mulvaney and Robbins 2011; Smardon 2009). According to the Millennium Ecosystem Assessment (Finlayson and others 2005), “the degradation and loss of wetlands is more rapid than that of other ecosystems,” and more than half of some wetlands in developed nations were lost in the twentieth century. One of those developed nations, the United States (Williams 2014), has lost much of its wetland area in one part of one state, the Louisiana coast, and that loss continues at an alarming rate (Couvillion and others 2011; Dahl 2011; Dahl and U.S. Fish and Wildlife Service. 2005; Williams 2014).

Among other ecosystem services, wetlands provide coastal communities in Louisiana with flood and erosion protection, water quality maintenance, and habitat for fish and wildlife, including species of commercial importance. Louisiana wetlands are a fundamental resource that helps protect infrastructure that provides the vast majority of U.S. offshore oil and gas, development that is home to more than two million people, and the nation's largest port complex. They also support nationally-significant commercial and recreational fisheries, and are habitat for millions of migratory waterfowl (America's Wetland Foundation 2014; Coastal Protection and Restoration Authority of Louisiana 2011; 2012b). As the state's Comprehensive Master Plan for a Sustainable Coast (2012) puts it, "Nowhere in the nation is there a region that simultaneously offers globally important habitat and the breadth of economic assets found in coastal Louisiana."

Canal Development and Results

Louisiana's coastal environment has been massively altered to support commerce. Indeed, it is often described as a "working coast" (Coastal Protection and Restoration Authority of Louisiana 2012b). That alteration includes a vast network of over 15,000 km of canals dredged for drainage, navigation, timber harvesting, oil and gas drilling, and pipeline construction (Day and others 2005; Day and others 2007). Canals are still the primary means of access into Louisiana wetlands, but they are also now recognized as a major contributor to a land loss crisis facing the state (Coastal Protection and Restoration Authority of Louisiana 2012b). Many of these canals do not currently serve the purpose for which they were originally dredged, and are of limited use in commerce (Turner and Streever 2002). Under or un-utilized canals are a threat to economic and other uses of the coast.

Canals and spoilbanks alter hydrology, and play both direct and indirect roles in Louisiana's land loss problem (Baustian and Turner 2006). Canal dredging replaces wetlands with open water channels and spoilbanks (Baumann and Turner 1990; Day and others 2000). Indirectly, spoilbanks restrict water flow above and below wetland surfaces (Swenson and Turner 1987; Turner and others 1988), and as a result cause both increased flooding and drying of adjacent wetlands (Swenson and Turner 1987; Turner and Streever 2002). This hydrologic alteration can limit sediment deposition (Cahoon and Turner 1989; Reed and others 2012), movement of nutrients and aquatic wildlife (Reed and Rozas 1995), stress vegetation, increase subsidence, and lead to wetland deterioration (Turner and Streever 2002). Other hydrologic impacts of canals and spoilbanks include the amplification of tidal prism volumes and increased saltwater intrusion (Gagliano 1973). Vegetation communities in wetlands adjacent to many canal dredging sites in Louisiana have changed or disappeared entirely as a result of these effects (Johnston and others 2009). Also, many canals and spoilbanks in the state are colonized by invasive exotic species such as water hyacinth (*Eichornia crassipes*), giant salvinia (*Salvinia molesta*), and Chinese tallow (*Triadica sebifera*).

While there is disagreement over the precise level of impact on Louisiana coastal resources that canals have created compared to other sources (Day and others 2000; Day and others 2001; Gosselink 2001; Theriot 2011; Turner 1997; 2001; Turner and Streever 2002), what is clear and widely recognized is that canals and their associated spoilbanks are significant drivers of wetland habitat conversion and land loss (Craig and others 1979; Day and others 2005; Day and others 2000; Johnston and others 2009; Turner 1987).

Canal Backfilling as Restoration

It is also recognized that canal backfilling-degrading and replacing the spoil adjacent to canals-is an underutilized part of the state's coastal restoration toolkit (Baustian and Turner 2006; Day and others 2005; Day and others 2007; Reed and Rozas 1995; Turner and

Streever 2002). Despite the severe and continuing damage done by canals, backfilling for the purpose of hydrologic and wetland restoration is uncommon in Louisiana.

Major hurricane impacts and the BP Deepwater Horizon oil spill have recently highlighted the extreme rate of ongoing land losses in the state, and brought home the value of Louisiana's wetlands to many. There is currently new emphasis on restoring the wetland landscape of coastal Louisiana, but there has been a marked lack of serious discussion regarding canal backfilling as an element of current restoration plans.

Louisiana's Comprehensive Master Plan for a Sustainable Coast (2012) prioritizes river diversion, marsh creation, and barrier island restoration projects. The master plan repeatedly recognizes the negative impacts of canals on the coastal environment, but remains silent with regard to canal restoration (Coastal Protection and Restoration Authority of Louisiana 2012b). Canal backfilling might be secondary to the major restoration techniques the plan does emphasize, but it could be an important component of overall restoration in the state's coastal zone (Day and others 2005; Day and others 2007).

Targeted canal backfilling has the potential to increase the function, sustainability, and resiliency of traditionally created wetlands. It does not make sense to refill wetland creation cells with dredged sediments at great expense while allowing the canals that hastened their collapse to persist. Canal backfilling in the influence areas of river diversions would improve their function by distributing diverted water more naturally across the landscape, instead of confining it to canals (Day and others 2005; Day and others 2007; Lane and others 2006).

Canal backfilling also provides benefits beyond improved hydrology and increased wetland resilience. Wetland creation, improved fish and wildlife habitat, and the removal of habitat for terrestrial invasive species are all additional important services provided by backfilling.

Finally, canal backfilling is relatively inexpensive when compared to the major restoration techniques that are the norm in Louisiana's coastal zone (Day and others 2005; Turner and Streever 2002), and would likely represent a nominal increase in overall project costs if integrated with primary restoration work.

Canal Backfilling Policy

The oil and gas industry and large landowners in Louisiana have been defensive about the perceived impact of canals and spoilbanks on the coastal landscape for decades. But, industry has also developed and successfully utilized measures to mitigate the impact of their activities on the coastal environment, including backfilling pipeline canals after construction. Beginning in the 1970s and 1980s, after recognition of the damage that pipeline canals caused in Louisiana coastal ecosystems, pipeline construction using smaller canals that were backfilled after the pipe was in place became common practice. However, older pipeline and oil and gas well drilling access canals remain largely unrestored as a result of the lack of industry and landowner support for actions, like backfilling, that would significantly alter the network of canals that exists on the landscape (Theriot 2011). This reluctance has its roots in long-held industry policies and perceptions, but is also a result of government policy barriers.

It is now relatively difficult to secure regulatory approvals to dredge new canals through undisturbed wetlands in the state. That is good for overall coastal health. But, current wetland protection policies also create disincentives for landowners in the coastal zone to backfill the canals on their property. Much of the exploitable value of the land still rests in subsurface minerals, and many of the canals in the coastal zone were originally dredged to provide access to those minerals. Preserving existing canals provides the potential for access that supports new exploration, or the development and production of previously uneconomic past discoveries. Backfilling recreates wetland acreage that would have to be mitigated for if backfilled canals were re-dredged, and could introduce large woody debris into canals, which would complicate re-dredging.

Canals and spoilbanks may have other value to landowners as well. Beyond their utility for access, canals are markers for property boundaries, habitat for species of management concern, and platforms for recreational camp construction (Turner and Streever 2002).

Mobilizing heavy equipment to complete the actual work of backfilling also represents a significant cost. Mechanisms for generating wetland mitigation credit that might defray those costs or create opportunities for profit are not streamlined, or cheap, and mechanisms for generating carbon credit are just beginning to become a reality (American Carbon Registry 2014; Kraft and others 2013).

There may also be issues with the perception of canal backfilling by regulators. While backfilling seeks to restore some of the damage done by dredging wetlands, it also creates wetland impacts and alters habitat in the process. Regulators were also full and enthusiastic participants in the creation of Louisiana's network of canals, many parts of which still facilitate significant economic activity. These factors help make it politically difficult to push for their restoration (Theriot 2014).

Research Purpose

This paper aims to answer some basic questions about the potential for canal backfilling in Louisiana coastal wetlands. I primarily sought to quantify how much spoil material might be available for use as canal backfill. Because the Louisiana coast is rapidly degrading, I wanted to identify spoil in relatively stable areas, or areas where other restoration is planned and could be improved by backfilling. I also attempted to identify spoil associated with canals that are not currently used in commerce, and spoil features that were large enough to be worth the cost of backfilling.

The resulting estimate of spoil material available for canal backfilling was used to describe the scope and geographic extent of backfilling opportunity in order to compare it to other planned restoration projects. I also developed some basic economic analyses using the estimate, and discussed policy.

DATA AND METHODS

I used geographic information systems (GIS) software (ArcGIS Desktop 10.1 Esri 2012) to identify and prioritize canal-related spoil material available for backfilling within the 1998 Louisiana Department of Natural Resources Conservation Plan Boundary (Louisiana Department of Natural Resources Office of Coastal Restoration and Management 1997), which is more specific to coastal wetland areas than the overall Louisiana Coastal Zone Boundary. The ModelBuilder application in ArcGIS was used extensively to create a workflow that is flexible, repeatable, and shareable (Esri 2014). My analysis was primarily based on 1988 coastal Louisiana habitat data produced by the United States Geological Survey's National Wetlands Research Center (USGS NWRC) (U.S. Geological Survey National Wetlands Research Center 2004).

Data Preparation

Rationale

The USGS 1988 habitat data was chosen as the primary basis for analysis because it includes upland habitats, identifies spoil as an attribute, and has extensive, if incomplete, coverage. Also, the 1988 habitat data is still the basis for most of the current National Wetlands Inventory (NWI) mapping for coastal Louisiana (U.S. Fish and Wildlife Service 2014), which allowed for a straightforward spatial adjustment that improved its alignment with other data.

Unlike the NWI, the 1988 habitat data maps upland habitats. Critically, this includes spoil disposal areas, which are artificially elevated, and in many cases delineated as uplands. These areas are removed by the U.S. Fish and Wildlife Service (FWS) during post-processing of the habitat data to create the NWI, which is solely focused on wetlands (U.S. Fish and Wildlife Service 2011). The inclusion of uplands and spoil attribute data made the 1988 habitat data an ideal starting point.

However, as mentioned above, the 1988 habitat data has incomplete coverage inside the Louisiana conservation planning boundary. The Martello Castle, Proctor Point, Pointe aux Marchettes, Lake Eugenie, Oak Mound Bayou, Mitchell Island, Lena Lagoon, Lake Eloi, Morgan Harbor, Morgan Harbor OE E, Lake Athanasio, and Point Chicot topographic quadrangles are not mapped, but contain wetlands in the area of interest. These quadrangles cover an area generally between Lake Borgne, Chandeleur Sound, and Breton Sound. Another way to identify spoil in this area was needed in order to achieve complete spatial coverage.

Spatial Adjustment

The first step in preparing the 1988 habitat data to make it more useful for analysis was a spatial adjustment based on the current NWI, which has better alignment with other data due to processing by the FWS. Links were created between matching polygons using vertex snapping, and a rubbersheet transformation was performed. At least one link was created in each topographic quadrangle that contained matching polygons, and a total of 588 links were placed.

Improve Spatial Coverage

To fill the data gap in the unmapped area between Lake Borgne, Chandeleur Sound, and Breton Sound, high resolution data mapping wetlands and water from the National Hydrography Dataset (NHD) (United States Geological Survey 2014) was used to selectively erase an otherwise featureless polygon (Figure 1). Removing wetlands and water left uplands in a multipart polygon which was then separated into singlepart features. The upland features derived in this way include spoil. This approach was not used in other areas because of the spoil-identifying attribute information available in the 1988 habitat data, because it underreports spoil areas in other parts of the coast-many of which are mapped as wetlands in the NHD, and because the derived polygons also include water due to NHD coverage issues (Figure 1). The output of this process is shown in Figure 2.

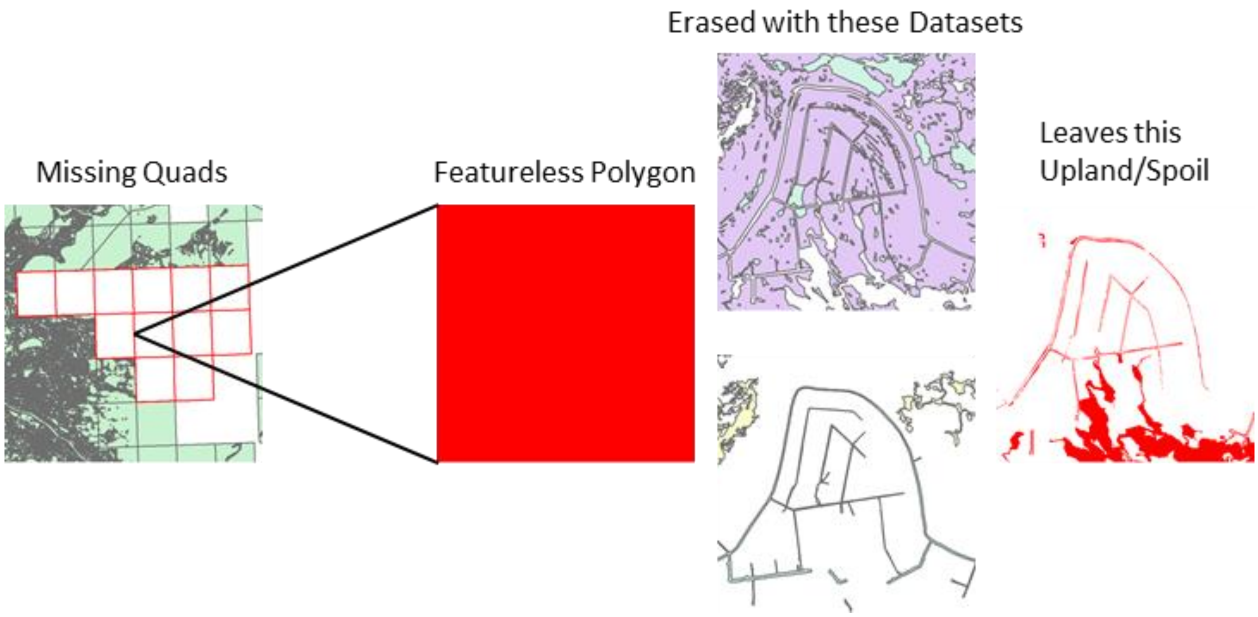

Figure 1. NHD-derived Spoil Workflow

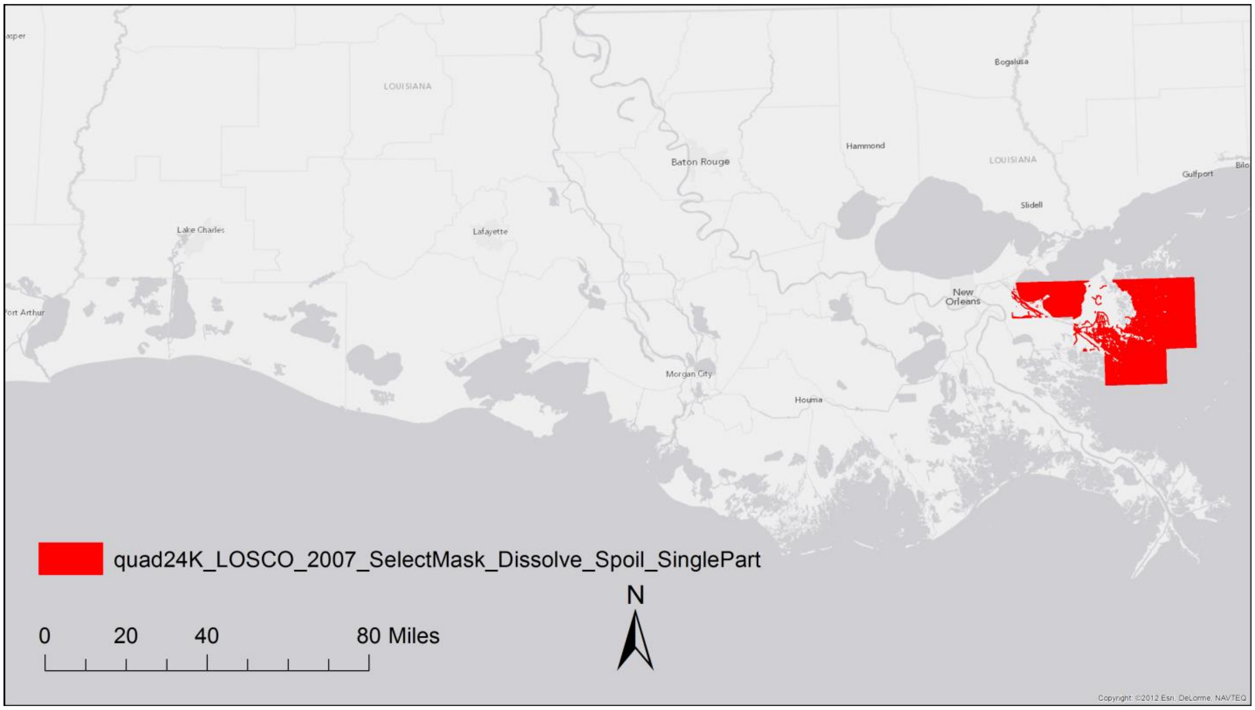

Figure 2. NHD-derived Spoil

Select Spoil Features

Rationale

As discussed above, the 1988 habitat data are an ideal starting point for analysis, but much change has occurred since then. Other information was required to improve its temporal coverage.

After the approval of its coastal zone management plan in 1980, the State of Louisiana began requiring permits for activities including dredging and spoil placement under coastal use permits (U.S. Department of Commerce National Oceanic and Atmospheric Administration 2014). Coastwide GIS data available from the Louisiana Department of Natural Resources Strategic Online Natural Resources Information System (SONRIS) details the spatial extent of many of these projects (Louisiana Department of Natural Resources 2014). Coastal use permit data are continually updated, so they can be used to bring the 1988 habitat data to the present.

Both datasets contain attribute information that makes it relatively easy to select spoil features.

Description of Analysis

The 1988 habitat polygons were first clipped to the 1998 conservation planning boundary. Polygons with spoil modifiers were selected, and a layer was created from the selection (Figure 3).

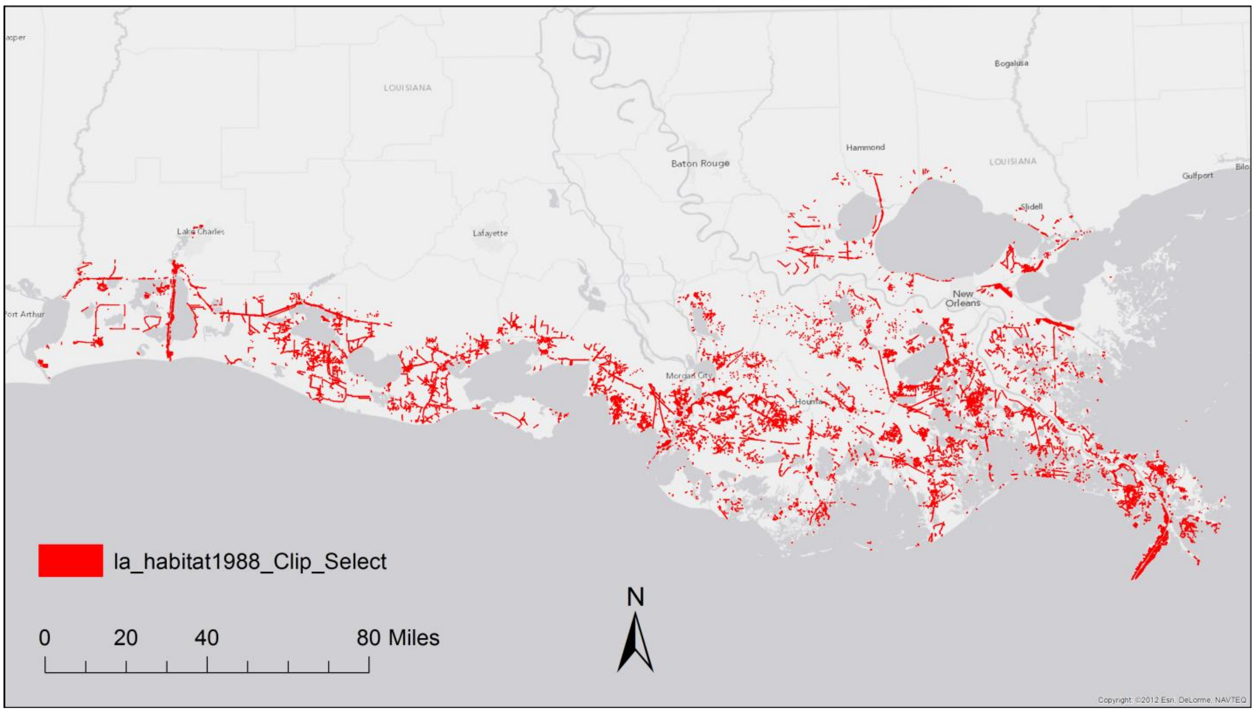

Figure 3. 1988 Habitat Spoil

Coastal use permit polygons downloaded 4/18/2014 were also clipped to the 1998 conservation planning boundary. Then a layer was created by selecting features representing projects involving spoil not associated with terraces, beneficial use, mitigation, marsh creation, spray dredging, or trenasses; or proposed, canceled, or withdrawn (Figure 4).

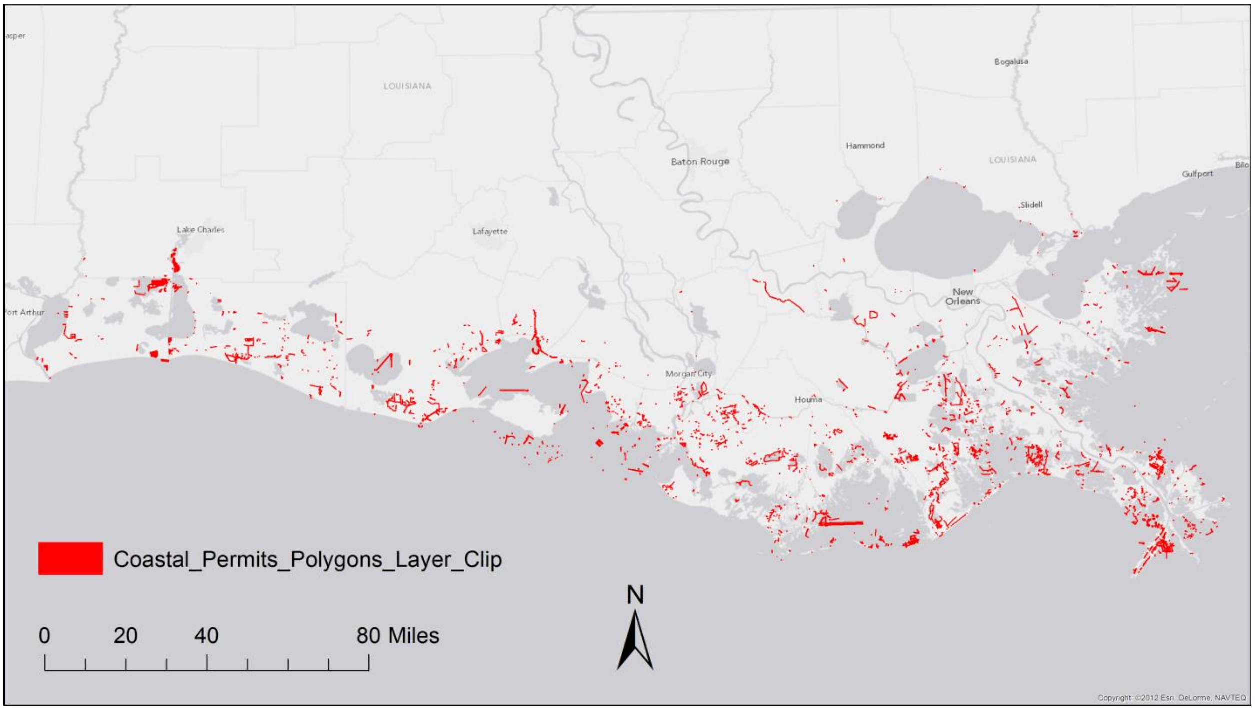

Figure 4. Coastal Use Permit Spoil

Merge, Dissolve, and Remove Non-linear Spoil Features

Rationale

Combining the spatially adjusted 1988 habitat data, coastal use permit data, and uplands derived from the NHD would result in a spatially and temporally complete dataset containing backfillable spoil features along with other data. For example, Louisiana coastal wetlands contain extensive spoil disposal areas that will not be used to backfill canals as contemplated in this report. That is, they were not linear spoilbanks immediately adjacent to canals that could be degraded and used as backfill. After combining the datasets, these areas were removed before further analysis.

Description of Analysis

All three layers were merged, and any overlapping polygon boundaries were dissolved. The merged and dissolved dataset was then refined by comparing the ratio of the perimeter to the area of the polygons (Shape_Length / Shape_Area >= 0.02). This extracted linear polygons that could be associated with canal backfilling. The resulting linear spoil polygons have a coastwide distribution, and a total area of approximately 40,719 hectares (100,618 acres) (Figure 5).

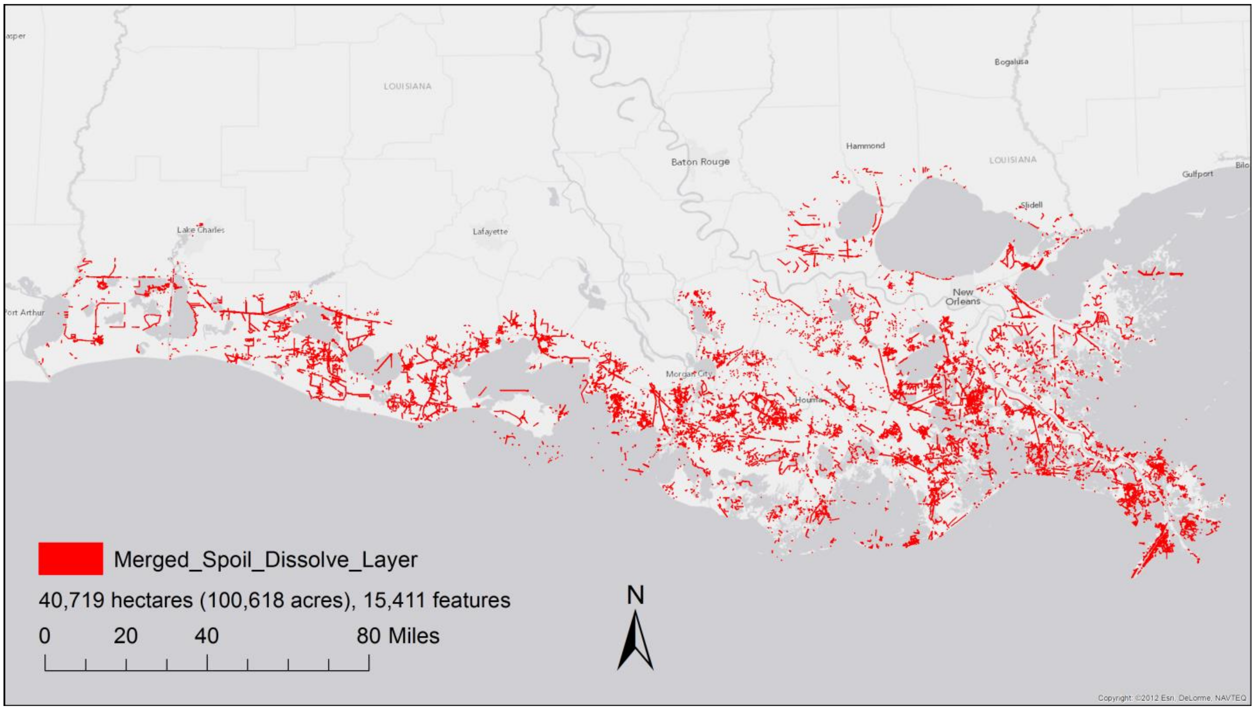

Figure 5. Merged Linear Spoil

Prioritization-Water and Projected Land Loss

Rationale

Canal backfilling, to the extent contemplated in this report, requires spoil elevated above the level of adjacent wetlands and the open water of canals. The USGS has estimated that Louisiana loses about 75 square kilometers of wetlands annually (Williams 2014), and losses, including spoilbanks, have certainly occurred since 1988.

If they remain, many areas of the coast have already lost, or will lose, land to such an extent that spoilbanks may be the only land left above water. Also, many coastal use permits authorized dredging in open water areas, and these linear features are included in the overall merged spoil layer even though they have no surface expression. The NHD-derived layer contained areas of water as well-though many were likely removed in the perimeter to area comparison step described above.

Therefore, many polygons within the overall merged spoil layer are actually open water, or projected to become open water relatively soon. My intent was to focus on backfilling opportunities in comparatively stable areas of the coast, so the process of refining and prioritizing the overall merged spoil dataset was continued by identifying areas of open water, as well as areas projected to become open water by 2050, from other sources.

Inspection of a number of datasets, including the NWI and the high resolution NHD, indicated that soils data contain some of the most detailed polygonal shorelines in the area of interest for this report. United States Department of Agriculture Natural Resources Conservation Service SSURGO (Soil Survey Geographic database) soils data are mapped at 1:24,000 scale (U.S. Department of Agriculture Natural Resources Conservation Service 2013), which matches the 1988 habitat data. This data provided the basic land/water boundary used to eliminate spoil features that were actually water.

The USGS NWRC and the United States Army Engineer Research and Development Center have produced several datasets that indicate Louisiana land/water boundaries and estimate land loss from the 1930s to the present (Barras and others 2008; Couvillion and others 2011; U.S. Army Egineer Research and Development Center 2014), and the NWRC has produced one that projects loss by 2050 (Barras and others 2003). Data derived from the latter was used to ensure that spoil features identified in this report were located in relatively stable parts of the coast by eliminating spoil features projected to become water by 2050.

Description of Analysis

SSURGO soil polygons for 20 coastal parishes were merged, and a layer was created from polygons mapped as water.

Data used to produce a poster of the projected land loss by 2050 (U.S. Geological Survey National Wetlands Research Center 2005) was converted from a floating-point to an integer raster, then to polygons. Layers containing polygons with water associated attributes in the year 2000, and projected wetland loss (conversion to water) between 2000 and 2050 were created.

The water data derived from soils mapping was then merged with the water and projected water derived from the raster to produce an overall water and projected water layer. Overlapping polygons were dissolved, and the result was clipped to the 1998 conservation planning boundary.

The water and projected water layer was then used to erase the linear spoil polygons, resulting in an approximation of the total spoil available for backfilling in relatively stable parts of the coast, approximately 22,166 hectares (54,772 acres). Note that this step removed about half of the area of the linear spoil polygons (Figure 6).

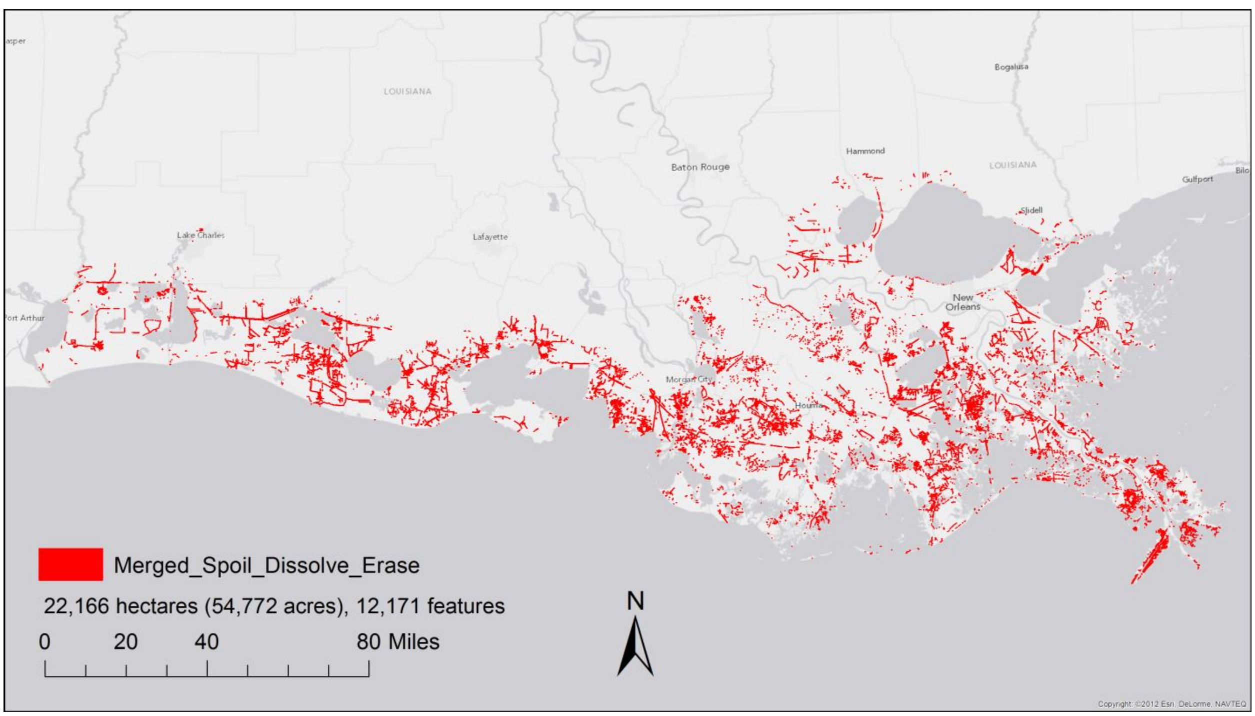

Figure 6. Merged Linear Spoil in Relatively Stable Areas

Prioritization-Area and Proximity

Rationale

The second major prioritization step was an attempt to identify spoil polygons large enough to be worth the effort and expense of mobilizing equipment to complete backfilling work (Turner and Streever 2002), and any remaining polygons within a reasonable operational area surrounding them, all else-access, land ownership, active or potentially active oil and gas infrastructure, navigation channels, etc.-being equal. The spoil layer resulting from the previous step in the analysis includes many polygons representing spoil areas that are fragmentary and isolated.

Description of Analysis

I identified spoil polygons above 4.05 hectares (10 acres) in size as well as any polygon below that size within 1 kilometer of larger spoil areas, and created a new layer based on the results. This layer is closer to the practically backfillable coastwide spoil area, and represents an area of approximately 18,333 hectares (45,301 acres). Many small, isolated features are removed in this step. While area is reduced by less than 10%, the number of individual features is more than halved, from 12,171 in the output of the previous step, to 5,518 (Figure 7).

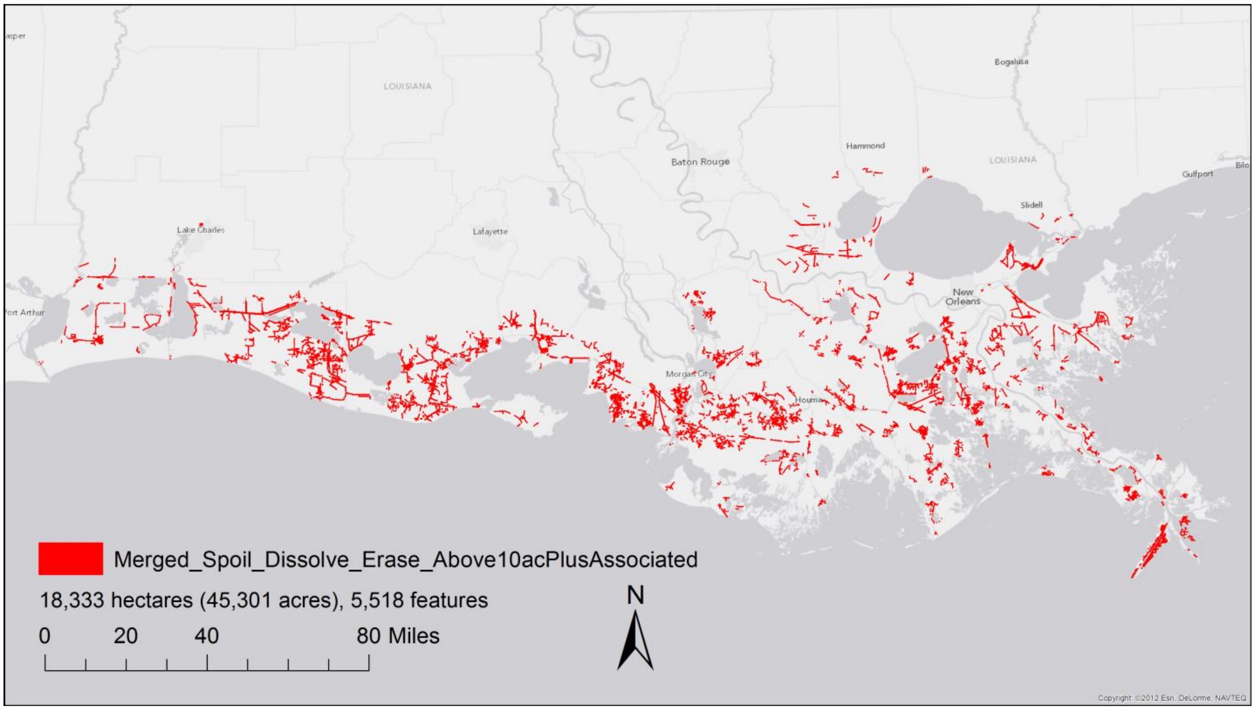

Figure 7. Spoil Selected by Area and Perimeter

Buffer Congressionally-authorized Navigation Channels

Rationale

Other practical considerations led to further refinement of the coastwide spoil data. Congressionally-authorized navigation channels are some of the largest and most hydrologically disruptive excavated features in the Louisiana coastal landscape, and are directly and indirectly responsible for much land loss (Louisiana Department of Natural Resources Office of Coastal Restoration and Management 1995).

These channels are not backfillable in the sense contemplated in this report, but large areas of spoil associated with many of them were still included in the spoil data to this point. Many marinas and boat ramps are also located on or in close proximity to the channels, and many smaller canals that could otherwise be candidates for backfilling are important for local navigation due to their connection and proximity to the large channels. Because the vast majority of Congressionally-authorized navigation channels will be maintained by dredging for the foreseeable future, they are also potential sources of additional backfill that could be added to nearby canals as a beneficial use of dredged material. Therefore, spoil polygons in the vicinity of navigation channels represent a special case, and they were separated before further processing and analysis.

Description of Analysis

A buffer distance from the centerline of each navigation channel based on channel depth was used as a rough mask for isolating associated spoil.

First, United States Waterway Data from the United States Army Corps of Engineers Navigation Data Center (U.S. Army Corps of Engineers Navigation Data Center 2014) was reprojected into the Universal Transverse Mercator coordinate system (Zone 15N NAD83 meters), and clipped to the 1998 Conservation Plan Boundary.

The reprojection provided an expedient way to generate a buffer distance in meters from centerline depth attributes, making the output of this operation consistent with other data produced during analysis. The buffer distance in meters equals the absolute value of the channel depth in feet multiplied by 50. Buffers generated this way vary between 50 meters in both directions from the centerline of channels within inland lakes to more than 2 kilometers from the centerline of Mississippi River passes.

The derived waterway buffers were then used to erase and clip the layer generated during the previous step, producing two layers-one, the clipped layer, associated with navigation channels (Figure 8), and one, the erased layer (Figure 9), which was not.

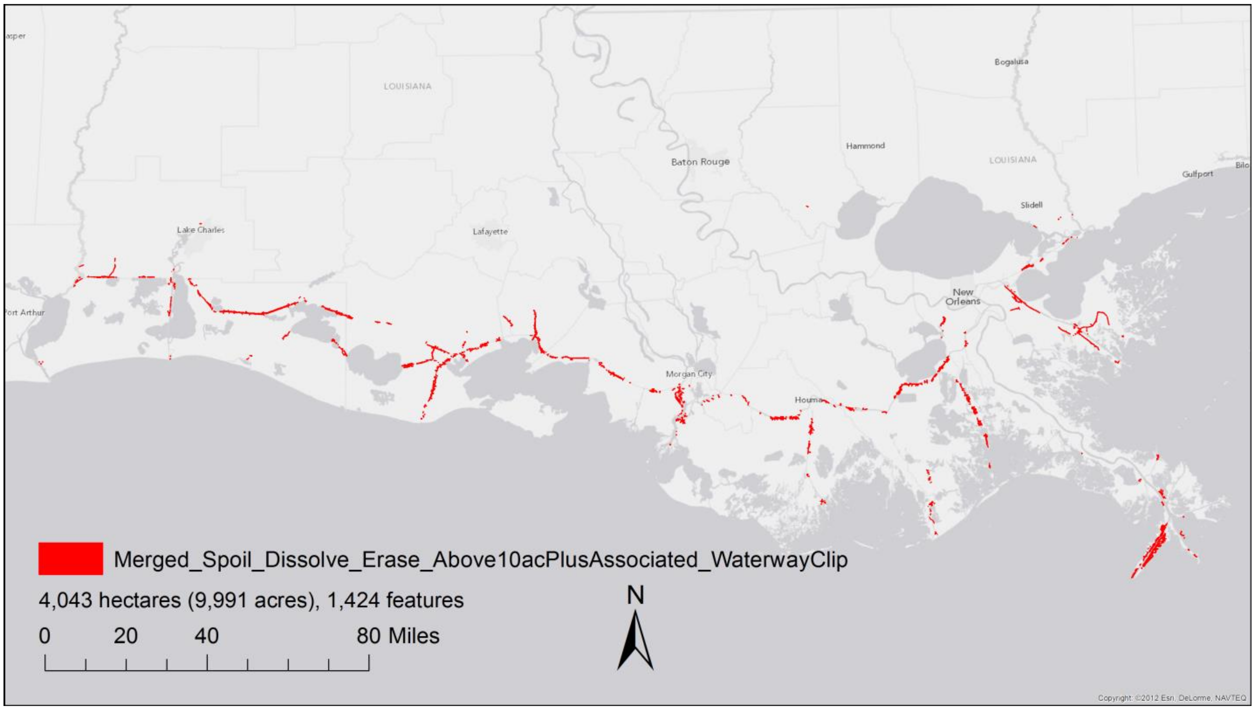

Figure 8. Spoil Associated with Navigation Channels

Unless otherwise stated, further analysis and discussion in this report is focused away from navigation channels (Figure 9).

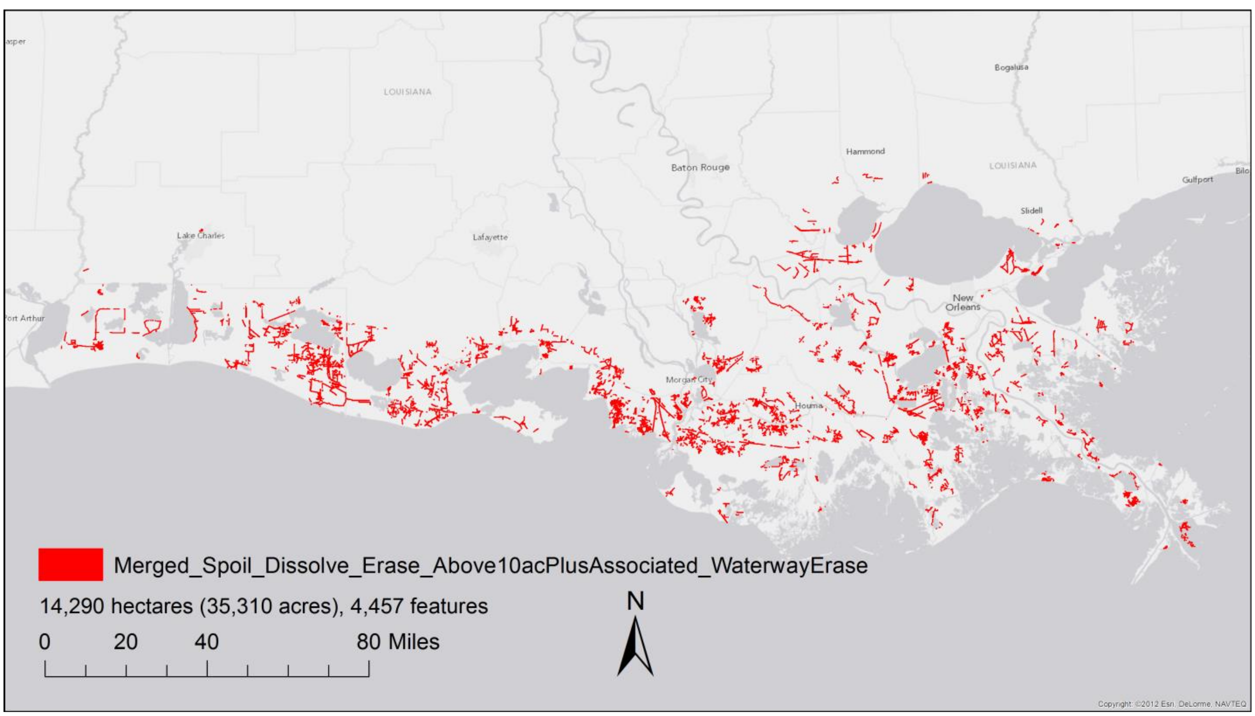

Figure 9. Spoil Not Associated with Navigation Channels

Oil and Gas Wells

Rationale

Active or potentially active oil and gas well infrastructure is associated with many canals, and they cannot be backfilled until operations cease. SONRIS provides detailed, continually updated well status information (Louisiana Department of Natural Resources 2014) that was used to further refine the spoil data.

Description of Analysis

The remaining spoil layer not associated with navigation channels was copied. Well data downloaded on 4/18/2014 were clipped to the 1998 coastal conservation boundary, and a new layer containing active or potentially active wells was created. Spoil features in the copied dataset within 100 meters of any active or potentially active wells were selected and then deleted. The spoil area derived from this step is 10,775 hectares (26,627 acres) (Figure 10).

This step is the last subtraction from the spoil data included in the analysis. The results represent the area and distribution of currently backfillable spoil in Louisiana's coastal wetlands. Further analysis parsed this dataset further to provide context and draw conclusions.

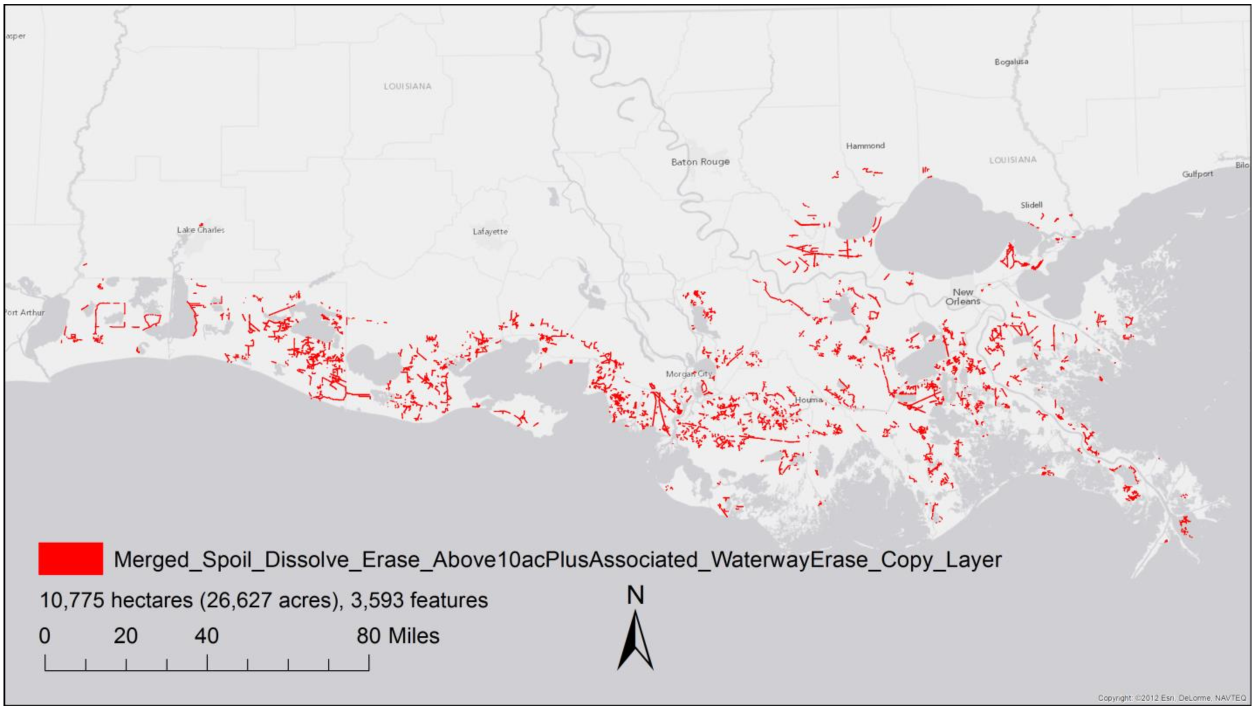

Figure 10. Currently Backfillable Spoil

Pipelines

Rationale

Pipelines represent a special case in that spoil can demonstrably be backfilled around them; as discussed in the introduction, industry has been doing similar work since the 1970s and 1980s. However, they are one more stakeholder that must be convinced of the merits of a backfilling project in order to proceed, and there are obvious safety concerns associated with working around active pipeline infrastructure with heavy construction equipment.

This is the first instance of analysis that does not add or subtract from the spoil data. Instead, pipeline data were related to the spoil dataset in order to provide context.

Description of Analysis

Pipeline data from the USGS (U.S. Geological Survey Biological Resources Division's National Wetlands Research Center 1999) within 100 meters of spoil polygons were spatially joined to the spoil data. This identified 1,232 hectares (3,045 acres) of pipeline associated features. Compare the joined selections in cyan to the remainder of the dataset (Figure 11).

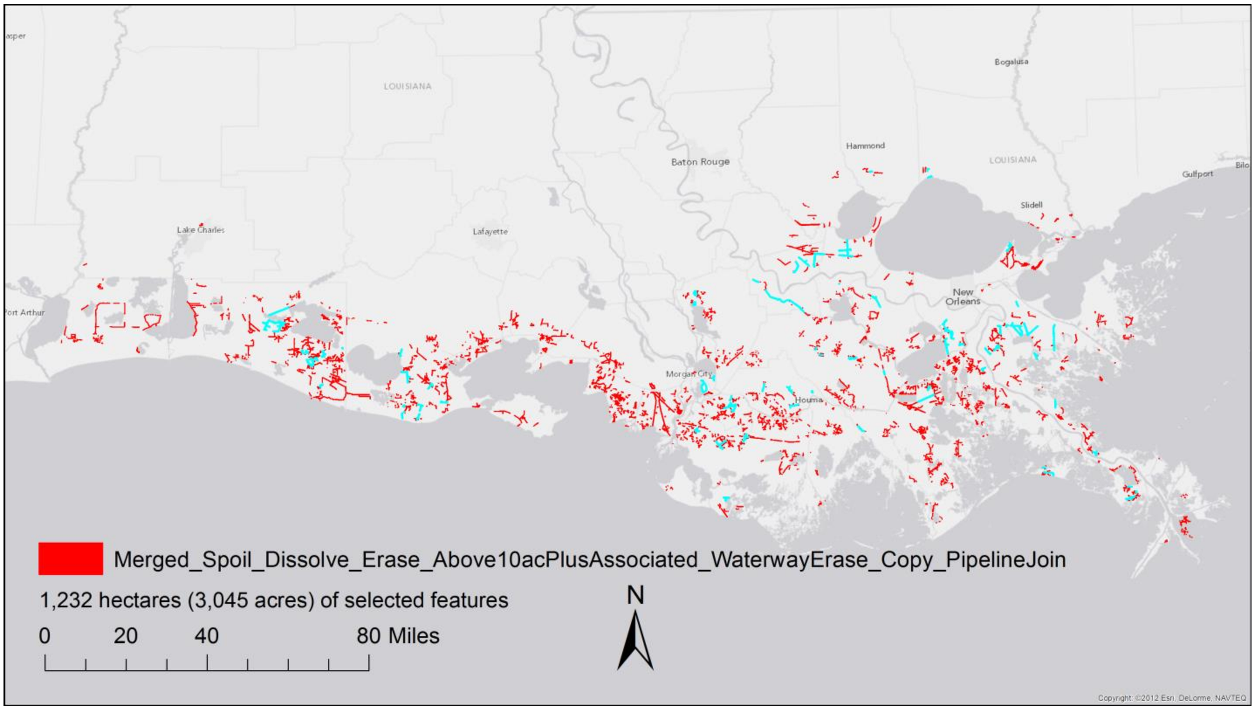

Figure 11. Pipeline-associated Spoil

Master Plan Project Features

Rationale

As discussed in the introduction above, canal backfilling could be an important part of other planned restoration projects, improving performance and saving costs. Comparing the scope and scale of restoration projects already supported by a wide variety of stakeholders to coastwide backfilling opportunity also provides context. Both of these analyses are useful in a discussion of coastal restoration policy.

Description of Analysis

Polygons representing project footprints approved as part of Louisiana's Comprehensive Master Plan for a Sustainable Coast (2012b) were obtained from the state's Coastal

Protection and Restoration Authority (Coastal Protection and Restoration Authority of Louisiana 2012a), and spatially joined where they intersected spoil polygons. The spatial join was followed by a dissolve to lump joined spoil features by project type. This identified 2,767 hectares (6,836 acres) of master plan project associated features. Compare the joined selections in cyan to the remainder of the dataset (Figure 12).

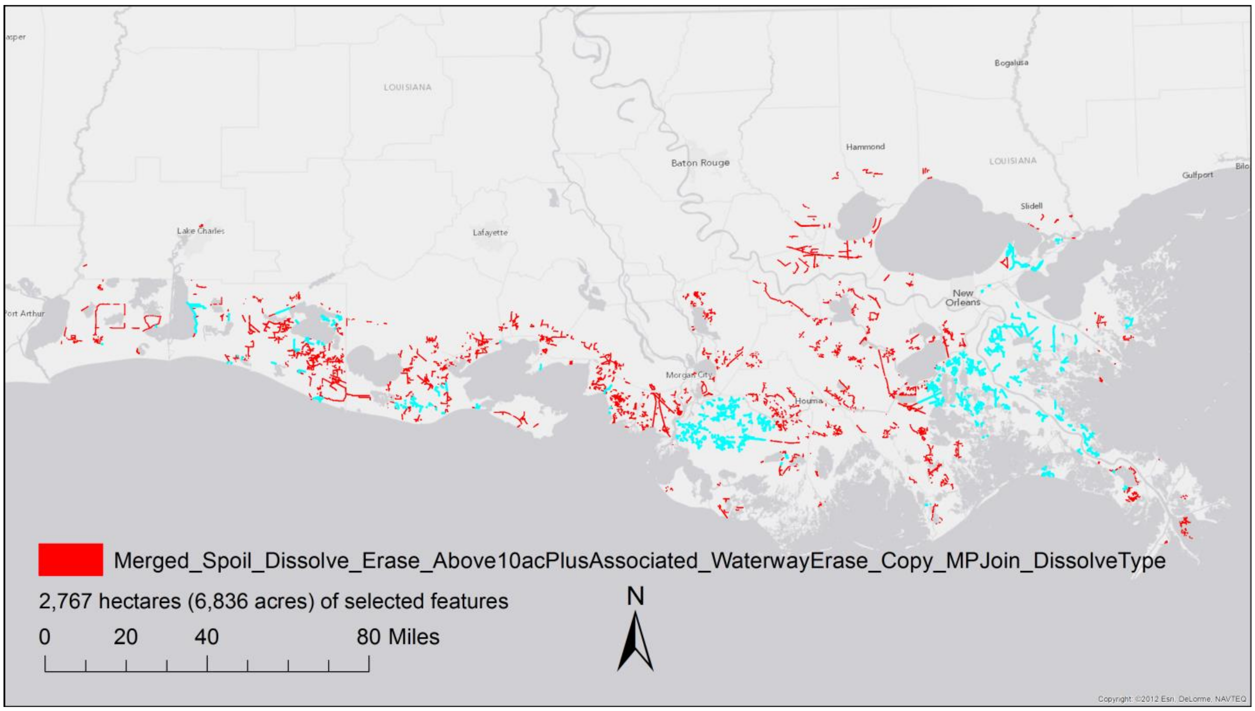

Figure 12. Master Plan Project-associated Spoil

Spoil Area by Hydrologic Basin

Rationale

Hydrologic basins represent natural divisions for a discussion of hydrologic restoration, though canal backfilling operates on a more local scale. Hydrologic basins also divide the coast in a manner that allows discussion of trends roughly oriented east and west along the shoreline of the Gulf of Mexico. Basin-scale decision-making is a feature of restoration project planning under the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) (Barras and others 1994), as well as compensatory wetland mitigation regulation (Buatt and others 2010). Indicating the potential scope and scale of canal backfilling opportunity in each basin should bring valuable context to a coastwide dataset, and provide an opportunity to speak to coastal restoration policy.

Description of Analysis

A spatial join based on NHD 8-digit hydrologic unit code boundaries, which correspond to major Louisiana coastal hydrologic basins, was created where those features intersected spoil polygons. Features in the resulting layer were then dissolved based on basin name to lump spoil features joined in the previous step. The results were further parsed to correspond to CWPPRA basin definitions, which differ slightly from the NHD, and to compare the western Chenier Plain to the eastern Delta Plain.

Spoil Area by Adjacent Habitat Type

Rationale

Broad descriptions of adjacent habitat type provide useful context for a study of canal backfilling opportunity in several ways. First, habitat types divide the coast in a manner that allows discussion of trends roughly oriented north and south between fastlands and the Gulf of Mexico. Second, descriptions of adjacent habitat types are useful for restoration planning. Third, adjacent habitat descriptions provide one basis for monetization of backfilling opportunity through wetland mitigation credit values, which are available based on broad habitat type.

Description of Analysis

Spoil features within 2013 vegetation type polygons mapped by the U.S. Geological Survey, Louisiana State University, University of Louisiana at Lafayette, and the Louisiana Department of Wildlife and Fisheries Coastal and Nongame Resources Division (Sasser and others 2014) were identified. This was followed by a dissolve based on vegetation/habitat type.

This was the final GIS analysis step completed for the project. The remaining methodology pulls from the results of the GIS analysis, but focuses on the economics of canal backfilling.

Economic Analysis

Rationale

As discussed in the previous analysis step regarding habitat, compensatory wetland mitigation provides an indication of the possible value of backfilling because prices for mitigation credits are available. It is also a potential pathway to financing canal backfilling work.

Ecosystem service value estimates for coastal Louisiana wetlands from literature are also available, and can also be used to monetize the value of canal backfilling. These estimates provide a value over time, which presents an opportunity to calculate the net present value of an investment in canal restoration.

Cost information from multiple estimates generally based on canal backfilling work by the National Park Service (NPS) in coastal Louisiana are available, and provide a counterpoint to the value of wetland mitigation credits and ecosystem service benefits discussed above.

Because restoration projects are a long term investment in coastal Louisiana, a net present value calculation was used to examine benefits versus costs for canal backfilling. Economic analysis provides additional context, and is useful in policy discussion.

Description of Analysis

<u>Benefits</u>

Mitigation values (per acre credit values) based on habitat type from the Louisiana Department of Natural Resources (Table 1) were averaged if presented as a range then multiplied by spoil area totals for each habitat type.

Table 1. Mitigation Credit Values (Buatt and others 2010)

Bottomland Hardwoods	\$17,582 to \$53,774/acre
Fresh Swamp	\$21,951 to \$70,000/acre
Fresh/Intermediate Marsh	\$45,000/acre
Brackish/Salt Marsh	\$80,000/acre

Costanza, Mitsch, and Day (Costanza and others 2006) estimated the value of Louisiana coastal wetlands at \$12,700 per hectare per year. This figure was multiplied by the total area of spoil to reach a restored ecosystem service value of coastwide backfilling.

<u>Costs</u>

A range of values have been developed regarding the cost of canal backfilling. Based on projects constructed in 2001 and 2002 and subsequent monitoring to determine restoration success, Baustian and others (2008) put the cost of backfilling at \$6,808 per acre. The NPS estimated a cost of \$22,466 per acre based on project construction costs from 2010, and an assumption that spoilbank area was proxy for restored area (Pate 2010). The United States Environmental Protection Agency estimated a cost of \$32,720 per acre in a 2010 CWPPRA proposal (U.S. Environmental Protection Agency 2010), and a cost of \$27,030 per acre over a longer time scale in a 2012 proposal (U.S. Environmental Protection Agency 2012). (Compare those estimates to the \$72,737 per acre for marsh creation in the master plan (Coastal Protection and Restoration Authority of Louisiana 2012a; 2012b).)

To produce a conservative estimate of the total coastwide cost of canal backfilling, spoil area was multiplied by the highest cost value available, \$32,720 per acre.

<u>Net Present Value</u>

Coastwide ecosystem service and cost values were then used to calculate a range of net present values over 50 years based on discount rates from 7% to 3%. The net present value calculation assumed all costs and no benefits at time zero, no costs and full benefits in every year thereafter.

RESULTS OR OBSERVATIONS

Current Coastwide Backfillable Spoil

The process of developing a representation of currently backfillable spoil across Louisiana's coastal landscape added GIS datasets together in an attempt to capture as much spoil area as possible, and then subtracted features from the result to focus on relatively large features not associated with navigation channels or active oil and gas infrastructure in relatively stable areas of the coast.

After selecting and merging linear polygons from the 1988 habitat data, coastal use permits, and NHD-derived uplands, the 15,411 features representing coastwide spoil area covered 40,719 hectares (100,618 acres). Removing water or potential water left 22,166 hectares (54,772 acres) in 12,171 features. Prioritizing by area and proximity reduced the spoil area further to 18,333 hectares (45,301 acres), while cutting the number of features by about 55% to 5,518.

The total area of the 4,457 spoil features not associated with Congressionally-authorized navigation channels is 14,290 hectares (35,310 acres). The 1,424 features associated with navigation channels cover an area of 4,043 hectares (9,991 acres). The difference in the feature totals between the sum of these two layers and their parent from the previous step is due to feature splitting at navigation channel buffer boundaries.

Removing features associated with active oil and gas infrastructure leaves a current practically backfillable spoil area of 10,775 hectares (26,627 acres) in 3,593 individual features.

Pipelines

Pipelines are a potential complication for canal backfilling projects, and were associated with 1,232 hectares (3,045 acres), or about 11% of the currently backfillable spoil area.

Master Plan Features

Master plan project areas intersect with 2,767 hectares (6,836 acres), or 26% of coastwide spoil features, which presents a significant opportunity for cost savings and improved performance through combining backfilling with other restoration.

Spoil Area by Hydrologic Basin

Spoil area by hydrologic basin gives a sense of how spoil is distributed roughly west to east along the Louisiana coast (Figure 13 and Figure 14).

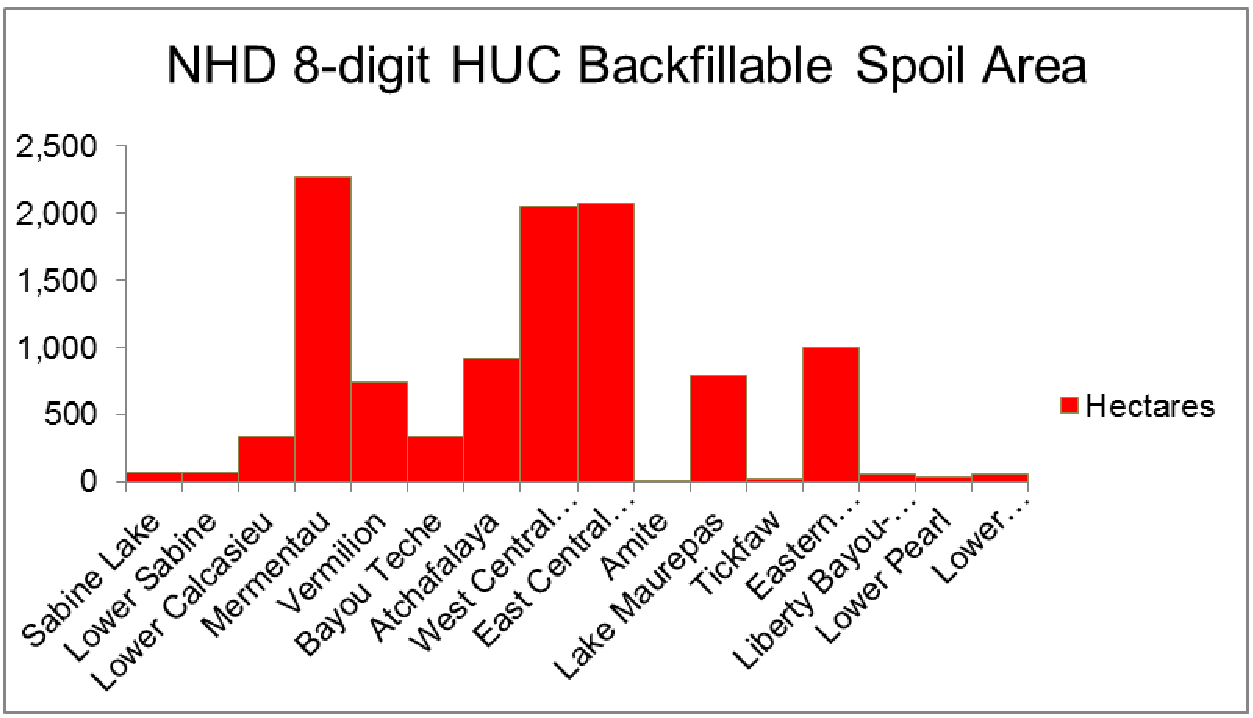

Figure 13. Backfillable Spoil by NHD 8-digit HUC Basin

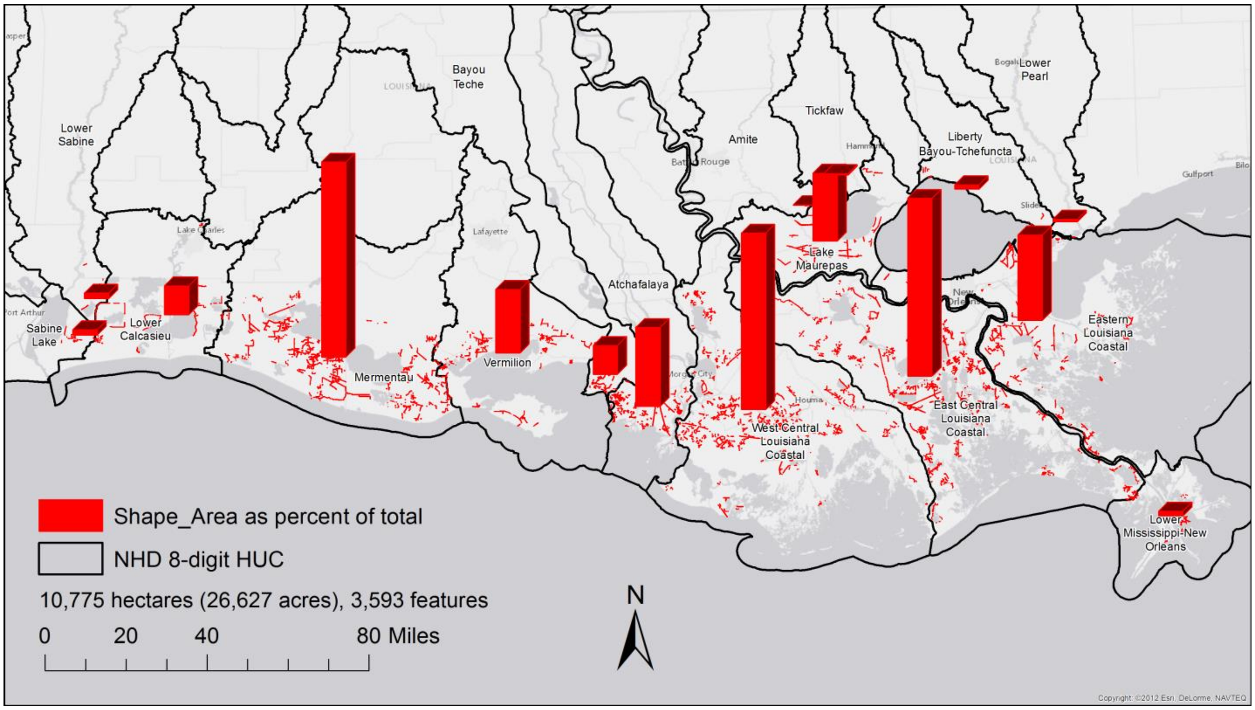

Figure 14. Backfillable Spoil by NHD 8-digit HUC Basin

Figure 15 lumps the totals into CWPPRA basins (Barras and others 1994), which are common areas of reference for Louisiana coastal restoration stakeholders. Lumping in this way also helps visualize patterns in the data. Three CWPPRA basins, the Mermentau, Terrebonne, and Barataria Basins, contain a roughly even distribution of a little more than 2,000 hectares each, or about 64% of the total coastwide backfillable spoil area.

Backfillable spoil has a roughly even distribution in other basins that make up the core of the coast as well. The Teche/Vermillion, Atchafalaya, Pontchartrain, and Breton Sound Basins all contain around 1,000 hectares of backfillable spoil. The western end of the coast contains significant backfilling opportunity too, with approximately 500 hectares in the Sabine/Calcasieu Basin, but the eastern and southern extremes of the coast, the Pearl (32 hectares) and Mississippi River (56 hectares) Basins, do not.

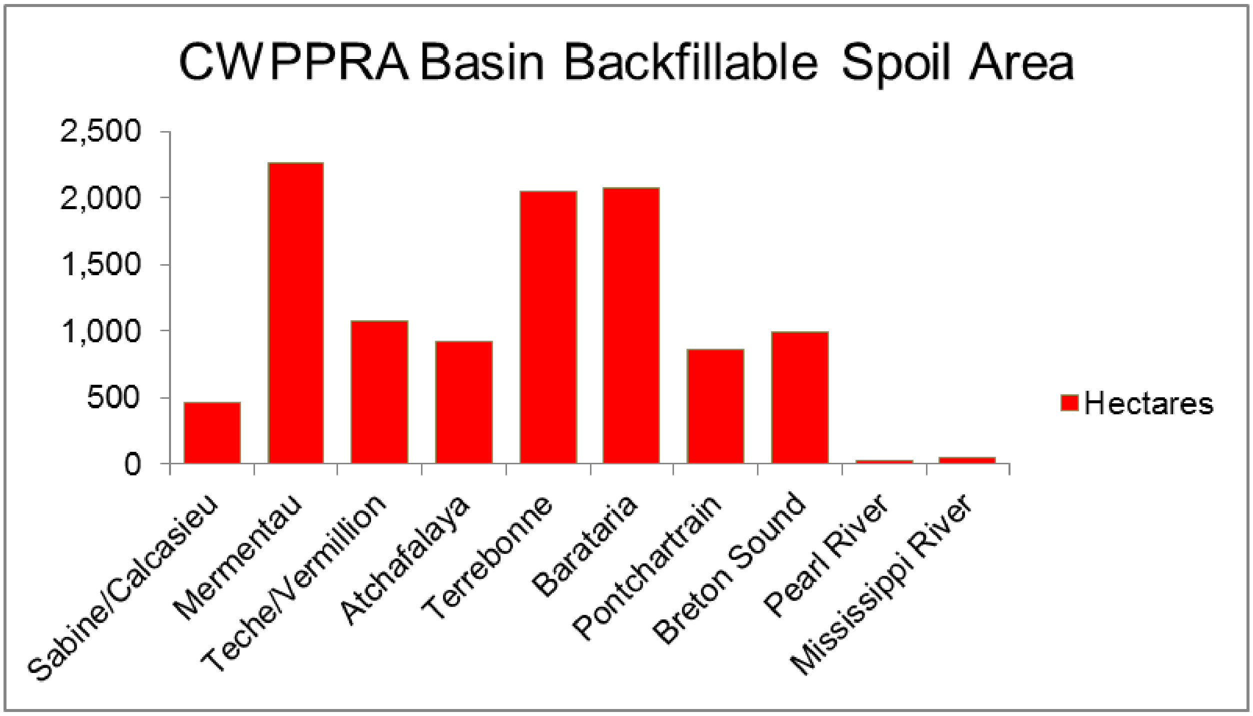

Figure 15. Backfillable Spoil by CWPPRA Basin

Lumping further, Figure 16 compares the backfillable spoil area in the Chenier Plain (the Sabine/Calcasieu, Mermentau, and Teche/Vermillion Basins) to the Delta Plain, which contains roughly double the area, or about two-thirds of the coastwide total.

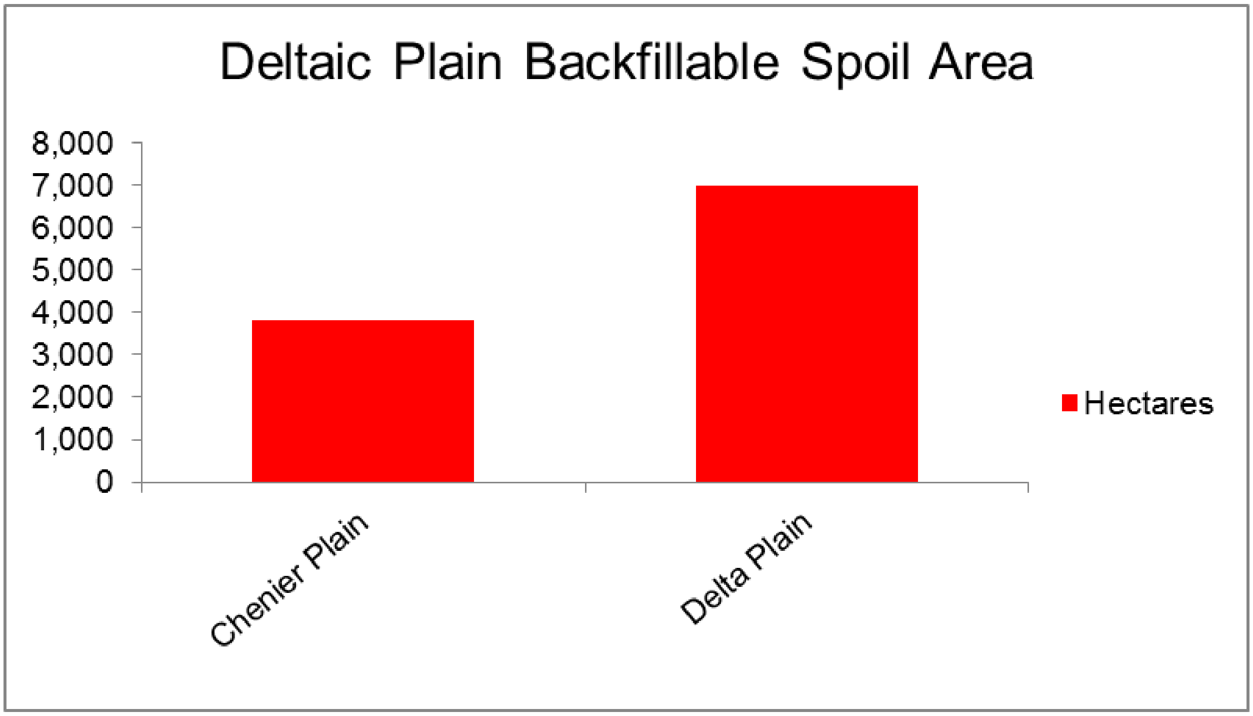

Figure 16. Backfillable Spoil by Deltaic Plain

Spoil Area by Adjacent Habitat Type

Adjacent habitat mapping can give us a sense of where backfilling opportunities are located along a generally north south salinity gradient that characterizes Louisiana coastal wetlands. Currently backfillable spoil area was primarily located adjacent to fresh and intermediate marshes (58% of total area), and in other areas even more removed from the influence of the Gulf of Mexico (Table 2, Figure 17, and Figure 18). Only about 17% of backfilling opportunity was adjacent to brackish or salt marshes. A negligible amount of spoil was mapped as water, which is likely due to the scale at which the vegetation types were mapped (1:550,000).

Table 2. Backfillable Spoil by Adjacent Habitat

Vegetation Type (Veg_code)	Hectares	Acres
Null (not mapped, assumed swamp)	706	1,744
O (other/non-marsh, BLH/swamp)	444	1,097
Swamp	1,606	3,969
F (fresh marsh)	3,316	8,194
I (intermediate marsh)	2,797	6,910
B (brackish marsh)	1,507	3,724
S (salt marsh)	374	924
W (water)	26	64

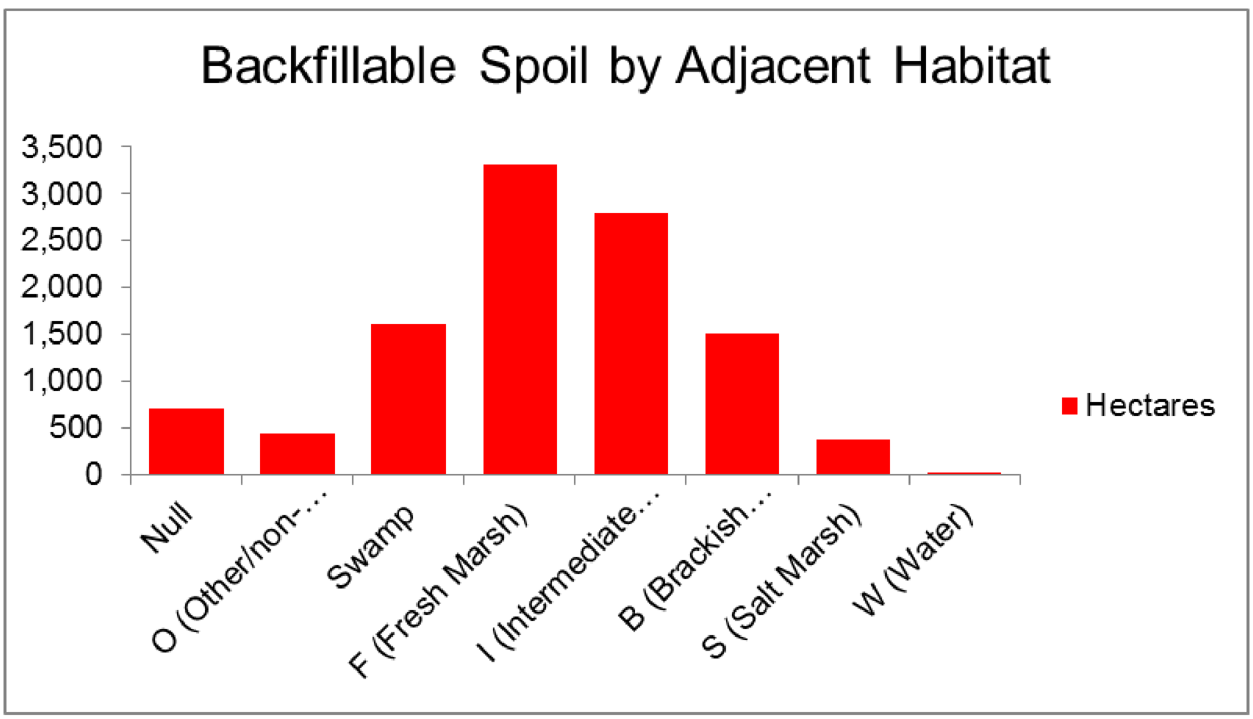

Figure 17. Backfillable Spoil by Adjacent Habitat

Economic Analysis

Benefits

Adjacent habitat mapping can also be used for an estimate of the value represented by backfilling opportunities based on wetland mitigation credit prices. Lumping adjacent habitats further (Figure 18), then multiplying by per acre values resulted in a total coastwide benefit of $1.33B (Figure 19). Roughly 51% of this value would be generated by backfilling canals adjacent to fresh or intermediate marshes.

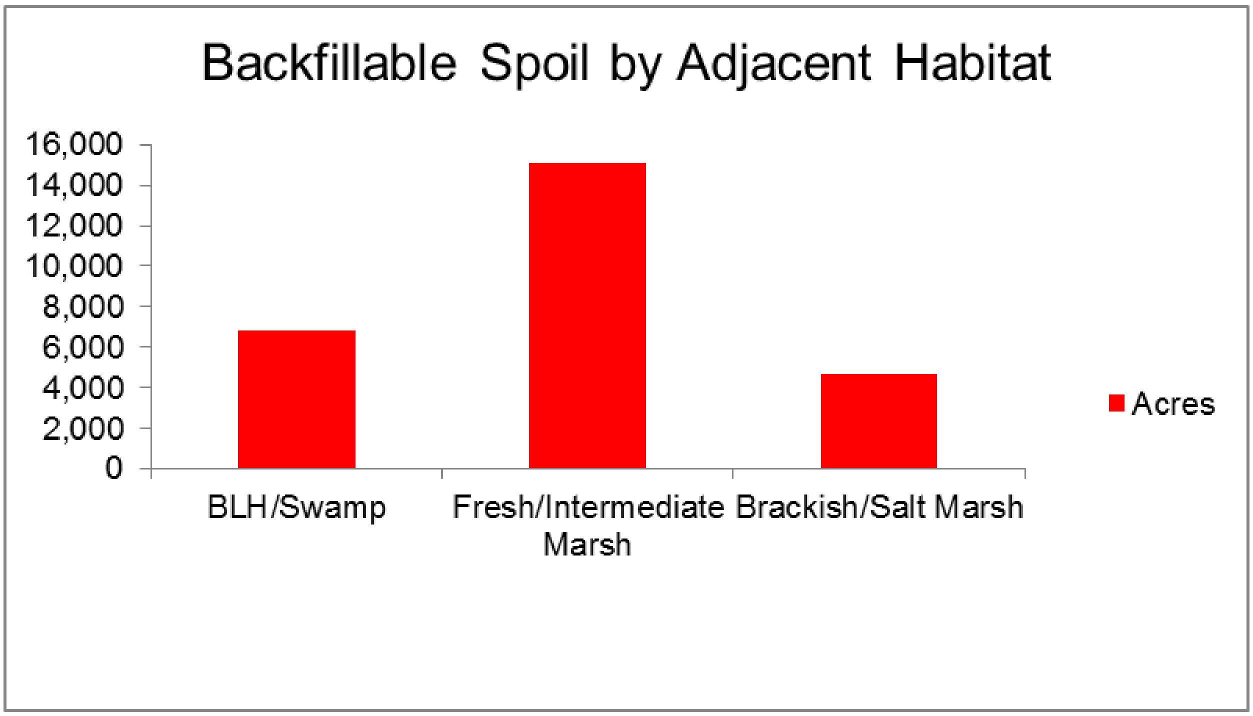

Figure 18. Backfillable Spoil by Adjacent Habitat

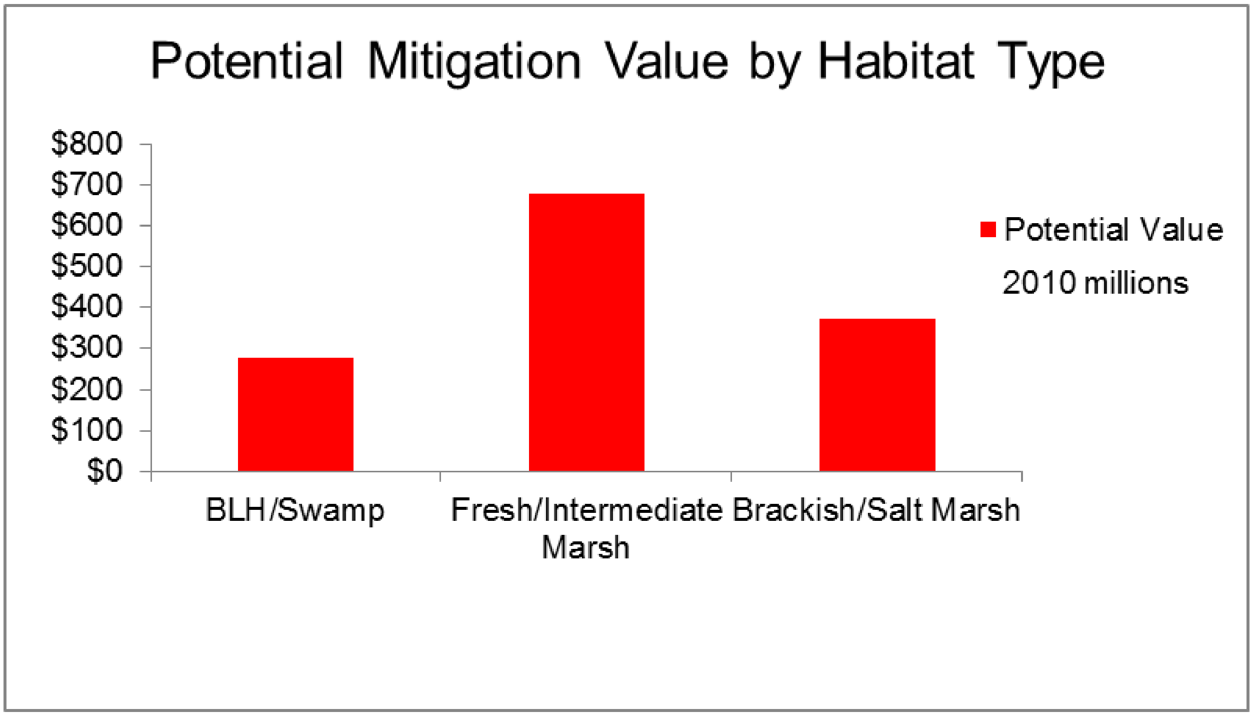

Figure 19. Potential Mitigation Value by Habitat Type

Looking at the $12,700 ha-1 yr-1 value of Louisiana wetlands from literature (Costanza and others 2006), the restored ecosystem service value of the coastwide backfillable spoil area is $0.14 billion per year.

<u>Costs</u>

Canal backfilling is cheap compared to other coastal restoration methods, but it still requires substantial investment. A conservative estimate from the EPA of $32,720/acre (U.S. Environmental Protection Agency 2010) was used to calculate the cost, $0.87B, associated with backfilling on a coastwide scale.

<u>Net Present Value</u>

Because canal backfilling would be a long term investment in Louisiana coastal health, its net present value was calculated. Based on the total ecosystem service value and cost discussed above at discount rates between 7% and 3%, a 50 year crash program of coastwide canal backfilling has a net present value of between $1.06B and $2.7B.

DISCUSSION

Major Findings

Opportunities for canal backfilling are comparable to the scope and scale of other wetland restoration projects contemplated in Louisiana. For example, the state's 2012 coastal master plan outlines about 19,500 acres of bank stabilization, oyster barrier reef, ridge restoration, and shoreline protection projects, and estimates the cost to construct these coastwide linear projects at $3 billion (Coastal Protection and Restoration Authority of Louisiana 2012a; 2012b). The currently backfillable spoil area identified in this report, 26,626 acres, is similar. That area could be backfilled for $0.87 billion based on the highest cost per acre estimate available.

Combining backfilling with other restoration projects represents an opportunity to improve their performance. Master plan 2012 features intersect 6,836 acres, or about 26%, of currently backfillable spoil. It is likely that savings from avoided mobilization/demobilization costs and other economies of scale would reduce the price of combined projects. Integrating backfilling with other projects would improve their performance.

Backfilling also represents an opportunity for coastal landowners because of the difference between wetland mitigation credit prices and backfill costs, and the coastwide ubiquity of backfillable spoil means that mitigation based on backfilling could be constructed in close proximity to wetland damage. The Louisiana Department of Natural Resources has criticized the lack of mitigation banks in the coastal area, as well as the distribution of those that do exist (Buatt and others 2010), and canal backfilling provides a means to address that problem.

Large landowners that have detailed information about oil and gas resources are in a uniquely advantageous position. They could plan and construct mitigation projects through backfilling while preserving access to resources in a way that is much more sophisticated than the analysis presented here, maximizing their return on investment while building resiliency across the landscapes they manage.

The societal benefits of building resiliency and more natural hydrology across the coastal Louisiana landscape by backfilling would extend beyond simply replacing spoil with more natural wetlands. But, just looking at the narrow local scale of backfilling impact-the conversion of prioritized spoil area to more natural wetlands-could generate billions of dollars of value for the State of Louisiana and its people.

One of those values would be economic activity directly attributable to backfilling-jobs. Louisiana has a maritime construction industry that helped build the canals, and the same equipment and skills can be used to backfill and restore them (Lowe and others 2011).

This analysis shows that even when selecting with a number of different criteria that reduce the number of features to be considered as candidates for canal backfilling, significant opportunities for restoration using the technique remain in Louisiana's coastal wetlands. This opportunity, and the ongoing degradation of the landscape it represents, is distributed throughout the coastal zone. Though pipeline construction since the 1970s and 1980s shows the willingness of industry to utilize backfilling and other methods to reduce impacts on a fragile and threatened environment, much remains to be done.

Only about 15 miles of canals have been backfilled for the purpose of restoration in coastal Louisiana (Baustian and Turner 2006; Pate 2010). The majority of these are canals that were dredged during the peak of oil and gas drilling activity in the coastal zone (Theriot 2011), a time when exploration and development were less sophisticated, wetlands were not valued in the same way they are now, and the negative effects of canals were not as well understood. Most of these canals are not currently utilized for their original purpose if they are used at all. No serious attempt to quantify and prioritize the opportunities for their restoration has been conducted on a coastwide scale until now.

Coastwide data analyses that support restoration planning are typically conducted at a resolution that precludes the consideration of features as small as typical oil and gas access canals or their spoilbanks. Basic datasets like land/water boundaries are produced at resolutions based on a 30m Landsat Thematic Mapper pixel (Barras 2009; Barras and others 2008; Coastal Protection and Restoration Authority of Louisiana 2012b; Couvillion and others 2011). Typical canal widths more or less match this value, and the water surface in them is often obscured by floating aquatic vegetation, which produces a return more like land than water. Typical spoilbank widths are less than 30m, often resulting in returns that are averaged with adjacent vegetation, water, or both.

This analysis used higher resolution data to construct simple models identifying and prioritizing canal backfilling opportunities on a coastwide scale. The models are flexible, can be shared, and are supported by GIS software that is widely available within academia, government, non-governmental organizations, and the private sector. Several of the datasets supporting conclusions receive continual updates, and major improvements to the primary dataset used in analysis are expected when the USGS NWRC completes circa 2008 coastal habitat mapping.

Finally, the negative effect of access canals for oil and gas drilling on wetlands has recently been tied to the sustainability of levee systems in a way that has raised the profile of the issue, and of canal backfilling (Jones Swanson Huddell & Garrison LLC 2014; Marshall 2013; Mufson 2013; Schleifstein 2013; Schwartz 2013). The Southeast Louisiana Flood Protection Authority-East has sued 97 oil and gas operators seeking compensation for wetland damage primarily attributed to unrestored canals that they argue diminishes their ability to operate and maintain the levee system protecting much of Greater New Orleans.

They also seek relief in the form of canal backfilling (Jones Swanson Huddell & Garrison LLC 2014). Such 'legacy lawsuits,' where landowners sue oil and gas operators for damages resulting from unrestored drilling and production activities, have been successful in Louisiana (Dismukes 2012; Louisiana Mid-continent Oil and Gas Association 2014).

SLFPA-E jurisdiction and the surrounding wetlands match closely with the Eastern Louisiana Coastal NHD 8-digit HUC basin. While the SLFPA-E lawsuit has gotten media attention (Jones Swanson Huddell & Garrison LLC 2014), this analysis indicates that three other similarly-sized basins, the East Central Louisiana Coastal (Barataria), Mermentau, and West Central Louisiana Coastal (Terrebonne), have more than double the outstanding legacy liability when measured by prioritized spoil area available for backfilling (Figure 13). Indeed, Jefferson and Plaquemines Parishes, which cover portions of the Barataria Basin, have also filed legacy lawsuits.

So, this report also has value to landowners, and individuals or businesses who have exploited oil and gas resources in Louisiana wetlands, as well as their advisors or advocates. Legacy liability is a reason more canal backfilling might be conducted by oil and gas operators in the state, but the status quo remains leaving canals on the landscape after operations cease.

Limitations

All of the GIS data used in this analysis has limitations, and the resulting data produced are only as good as the most limited input. Examples of such limitations include the scale to which vector data were mapped, and the resolution of rasters. In general, data analyzed in this report were mapped to 1:24,000 scale, a standard based on USGS topographic quadrangle maps. Therefore, GIS data products associated with the report should not be used for analysis at larger scales.

Another limitation of the GIS inputs includes the spatial and temporal completeness of data. The primary base dataset, 1988 USGS habitat data, was both spatially and temporally incomplete, and had alignment problems with other data. These were mitigated in the data preparation phase, which introduced error. Some further processing, like removing "spoil" polygons that were actually open water, was designed to mitigate those errors in turn, but not all errors could be resolved. For instance, though the 1988 habitat data was closely aligned with the current NWI, I could not match the post-processing completed by the FWS to produce the NWI exactly. This issue was compounded in the eastern part of the state, where the NWI is based on more recent habitat mapping that does not match the 1988 habitat data. Alignment issues there could not be resolved. The secondary source used to mitigate temporal accuracy issues is based on coastal use permit records, which most often delineate proposed, not as-built, project footprints, and should tend to overestimate spoil areas.

Finally with regard to GIS data inputs, any errors in the data were incorporated into the analysis. Therefore, GIS data resulting from this analysis should be used with caution, and an understanding of the limits of the inputs.

A further major limitation of the analysis described in this report is poor association of spoil and canal segments. That is, poorly defined relationships between all of the spoil polygons associated with a particular canal to each other, and to the canal. The use of spoil as the basis for analysis mitigates this issue somewhat because spoil polygons tended to be more discrete than canal features in the datasets utilized or examined.

Discrete polygons present their own issues. For instance, a common limitation of the spoil data involved noncontiguous spoilbanks on each side of the same canal mapped as separate features. Some analyses, like prioritization based on area, would be more effective if these polygons were part of the same multipart feature.

The reverse is also true. Another common limitation of the spoil data involved what should have been separate canal segments with contiguous spoilbanks that were mapped as a single polygon. Polygonal water datasets were similarly constrained, but even more so. Analyses like the active oil and gas well selection would be more effective if these features were separated.

The contradictory and overlapping potential of features near Congressionally-authorized navigation channels was not resolved in this report. Also, features located near high wave energy environments, like navigation channels, but including lakes and other large water bodies, were not identified as a special case of their own. These features may be more resistant to erosion if left unbackfilled. Plans for backfilling work near high energy environments should include consideration of the effects of wave energy (Turner and Streever 2002).

All analyses were made without regard to land rights, the intent of land managers, special mandates, or other values associated with the legal and practical landscape that overlaps the area of interest. So, while the analysis can point to canal backfilling opportunity on a particular piece of property, and make general statements about the value of restoration to the landowner and to society, there may be valid legal, economic, or practical reasons for never backfilling there. This paper points out the substantial overlap between canal backfilling opportunity and already planned restoration because effort towards those projects that includes backfilling from the beginning would mitigate many of these issues.

Spoil area is used as a proxy for the restorable area of wetlands by backfilling in this report. In practice, backfilling success as measured by wetland area created depends on a number of different factors, and is variable (Baustian and Turner 2006).

All information on the cost of backfilling presented in this report is derived from projects constructed by the NPS in 2010. The analysis of benefits and costs presented is very simplistic.

Relationship to Other Studies

This project drew on basic principles from studies and reviews of Louisiana canal backfilling projects like the general use of spoil area as a proxy for wetland area restorable (Baustian and Turner 2006; Turner and Streever 2002). It relied heavily on GIS datasets produced by the USGS NWRC.

The project is unique in that it examines, quantifies, and prioritizes opportunities in Louisiana wetlands on a coastwide scale. A non-governmental organization, the Gulf Restoration Network, recently analyzed backfilling opportunities in portions of the Barataria and Terrebonne Basins using a different approach that relied on digitizing each of the canal and spoilbank features by hand (Eustis 2014). The NPS has produced a plan and environmental assessment that identifies canals within the 23,500-acre Barataria Preserve unit of Jean Lafitte National Historical Park and Preserve for backfilling (U.S. Department of the Interior National Park Service 2010). These studies are the most directly comparable examples I am aware of, but they do not present a coastwide perspective.

Suggestions for Further Research

One of the main limitations of this analysis was poor association of spoil and canal features. Future research that could resolve this problem would improve analyses based on discrete features, like oil and gas wells. Analysis that correctly identifies all of the canal segments that provide access to a particular well is even more of a challenge. Modeling hydrology associated with canals, or using existing data like the NHD, might be a way to accomplish both of these aims.

The valuation of benefits and costs presented in this report is very simplistic, but the analysis could be a starting point for more sophisticated research. Considering the paucity of projects on which to base analysis, further examination of the benefits and costs of backfilling could incorporate information from other coastal construction projects that use similar personnel and equipment. Data produced in this report or updates based on similar methods could then be used to provide estimates of the scale of backfilling opportunity. Also, because they are spatially referenced, the data produced for this report could be used to look more closely at mobilization/demobilization costs by comparing the distance from developed areas, launches, etc. with spoil features. The results could further refine priorities for backfilling coastwide.

Resolving the complications surrounding navigation channels could also refine coastwide backfilling priorities. Improved feature association as discussed above could help with this, and other datasets, like Louisiana Marinas and Boat Launches from the Louisiana Oil Spill Coordinator's Office (2004), could be used to further select and remove canals used in local navigation from the data.

Conclusion

Canal backfilling is a way to achieve coastal restoration on a similar scale to other linear projects already included in approved plans at a significant discount. It would be a cost-effective step in creating a sustainable and resilient coast for Louisiana's future. Louisiana currently has both a need and an opportunity to complete major restoration projects coastwide, and backfilling should not be ignored when considering the portfolio of projects to be constructed. This is especially true where opportunities to backfill canals overlap with other projects.

Canal backfilling also represents an opportunity for the state and industry to resolve political and legal difficulties, and would make the existing disconnect between recognition of the negative impacts of canals and substantive action to repair the damage they continue to cause a thing of the past.   Finally, it could be an opportunity for private entities to profit-all from wetland and hydrologic restoration that benefits society in other ways.

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